NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3812

FLIGHT INVESTIGATION OF THE STABILITY AND CONTROL CHARACTERISTICS OF A VERTICALLY RISING AIRPLANE RESEARCH MODEL WITH SWEPT OR UNSWEPT WINGS AND ×- OR +-TAILS

By Robert H. Kirby

Langley Aeronautical Laboratory
Langley Field, Va.

Washington

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This paper presents the results of an investigation of the dynamic stability and controllability of a propeller-driven vertically rising airplane model which had swept or unswept wings and cruciform tails with ×- or +-orientation. The investigation consisted of hovering flights in still air at a considerable height above the ground, hovering flights very close to the ground, vertical take-offs and landings, flights through the transition range from hovering to normal forward flight, and sideways translational flights. It was found that there were no major differences in the behavior of any of the model configurations, and in general they could all be flown fairly easily in either hovering or transition flight.

INTRODUCTION

An investigation has been made by the Langley Free-Flight Tunnel Section to determine the dynamic stability and control characteristics of a general-research propeller-driven vertically rising airplane model which had swept or unswept wings and cruciform tails with ×- or +-orientation. The model represented approximately a 1/8-scale model of a fighter-type vertically rising airplane. The model had large counterrotating propellers powered by a 5-horsepower electric motor. Control was provided by conventional flap surfaces operating in the propeller slipstream.

The investigation included hovering flights in still air at a considerable height above the ground, hovering flights very close to the ground, and vertical take-offs and landings. Flight tests were also made to study the stability and control characteristics of the various configurations during slow constant-altitude transitions from hovering to normal forward flight, and in sideways translational flight. Since there were four configurations and many test conditions for each, and since testing time was limited, particularly tunnel time for the transition tests, the investigation was necessarily of a general nature. The results consisted primarily of the pilots' observations of the stability and controllability of the model. In some cases, however, time histories of the motions of the model were obtained from motion-picture records of the flights.

NOMENCLATURE AND SYMBOLS

The terminology used in this paper in referring to the model motions at all angles of attack is the same as that used for a conventional airplane with respect to the body system of axes shown in figure 1. Angular displacement about the fuselage (X) axis is referred to as roll, angular displacement about the spanwise (Y) axis is referred to as pitch, and angular displacement about the normal (Z) axis is referred to as yaw. Figure 1 shows the positive directions of the forces, moments, and linear and angular displacements.

The definitions of the symbols used in the present paper are as follows:

c	wing chord, ft
h	height of landing gear above ground, ft
I_X	moment of inertia about fuselage axis, slug-ft^2
I_Y	moment of inertia about spanwise axis, slug-ft^2
I_Z	moment of inertia about normal axis, slug-ft^2
M_X	rolling moment, ft-lb
M_Y	pitching moment, ft-lb
M_Z	yawing moment, ft-lb
t	time, sec
V	tunnel airspeed in forward-flight tests, knots

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M_X	rolling moment, ft-lb
M_Y	pitching moment, ft-lb
M_Z	yawing moment, ft-lb
t	time, sec
V	tunnel airspeed in forward-flight tests, knots

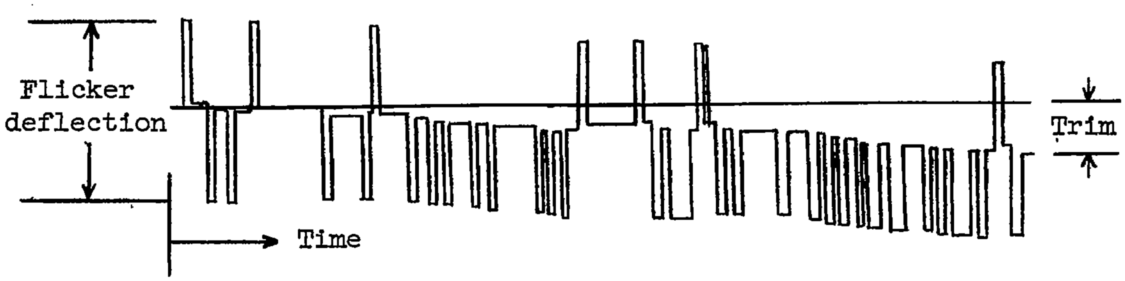
X	fuselage axis
Y	spanwise axis
y	displacement along Y-axis, ft
Z	normal axis
z	displacement along Z-axis, ft
α	angle of attack, deg
δ_a	aileron deflection, deg
δ_e	elevator deflection, deg
δ_r	rudder deflection, deg
θ	approximate angle of pitch of thrust axis relative to horizontal, deg
ϕ	approximate angle of roll, deg
ψ	approximate angle of yaw, deg

APPARATUS AND TESTS

Model

The model represented approximately a 1/8-scale model of a fighter-type vertically rising airplane and had swept or unswept wings and cruciform tails with $\times$- or $+$-orientation. A photograph of the model with the unswept wing and $\times$-tail is shown in figure 2. Drawings of the model, along with tables giving the geometric characteristics of the different components, are shown in figure 3. Figure 3(a) shows the unswept wing and the $\times$-tail while figure 3(b) gives the details of the swept wing and the $+$-tail. The model had an 8-blade, counterrotating, fixed-pitch propeller (two 4-blade elements in tandem) powered by a 5-horsepower electric motor, the speed of which was changed to vary the thrust. The model was provided with landing shock struts at the tips of the tail which used metered oil damping and an air spring. The wire propeller guard, shown in the photograph of figure 2, prevented the slack in the flight cable from becoming fouled in the propellers during flight. The curved steel rod, which extended from the nose of the model around the propeller guard to a point on the fuselage near the center of gravity, was part of the safety-cable system which is explained in the section entitled "Test Equipment and Setup."

When equipped with the +-tail the model had conventional flap controls operating in the propeller slipstream - ailerons on the wings, elevators on the horizontal tail, and rudders on the vertical tails. With the ×-tail mounted on the model, however, all four tail controls moved to give either pitch or yaw control, and roll control was provided by the ailerons on the wing. The control surfaces were remotely operated by the pilots by means of flicker-type (full-on or off) pneumatic actuators which were controlled by electric solenoids. These actuators were equipped with an integrating trimmer which trimmed the control a small amount in the direction the control was moved each time a control deflection was applied. An explanation of the control plots contained in most of the flight records is as follows:



The horizontal line is a reference line which has its origin, not necessarily at 0° deflection, but at the control trim position required for hovering flight. The flicker deflection is the control deflection applied by the pilot. Each time a flicker deflection is applied the control is trimmed a small amount in that direction, so that if the control is deflected more times in one direction than in the other a change in trim occurs. The trim change is indicated at the right of the plot.

The weight and moments of inertia of the model were:

Weight, lb	40
I_X, slug-ft^2	0.35
I_Y, slug-ft^2	1.65
I_Z, slug-ft^2	1.78

Test Equipment and Setup

The take-off, landing, and hovering tests were conducted in a large building which provided protection from the random effects of outside air currents. The transition from hovering to forward flight and the sideways flight tests were conducted in the Langley full-scale tunnel.

The test setup used in the take-off, hovering, and landing tests is illustrated in figure 4(a). The power for the motor and electric solenoids and the air for the control actuators were supplied through wires and plastic tubes. For most of the tests the wires and tubes were suspended from above and taped to the safety cable from a point about 15 feet above the model down to the model itself. The safety cable, which was attached to the nose of the model for the hovering tests, was used to prevent crashes in case of control failure. For a few of the tests the flight cable was allowed to trail downward from a point near the center of gravity to determine whether the cable configuration had any significant effect on the flight results. Only the safety cable came in from above in these tests.

The test setup for the transition tests in the Langley full-scale tunnel is illustrated in figure 4(b). The arrangement of the power and control cable and the safety cable was similar to that for hovering except for the attachment of the cables to the model. For the transition tests, a curved steel rod was attached to the nose of the model and to the fuselage at a point near the center of gravity as shown in figure 5. The cable was attached to a pulley which could run on the steel rod from the nose to a point near the center of gravity as the model went from hovering to forward flight. With this setup, the line of action of the drag of the flight cable passed approximately through the center of gravity of the model and did not cause large pitching moments when the model was in forward flight.

For most of the tests, separate pilots were used to control the model in pitch, roll, and yaw in order that they might give careful attention to studying the motions of the model about each of the axes. A few hovering flights were made in this investigation, however, with one pilot operating all the aerodynamic controls to demonstrate the controllability of the model with a single pilot. Two operators in addition to the pilots were used in flying the model - one to control the power to the propellers and one to operate the safety cable to maintain a reasonable amount of slack.

Tests

The investigation consisted entirely of flight tests to study the stability and control characteristics of the various configurations of the model. The stability and controllability were determined in various tests either qualitatively from the pilots' observations or quantitatively from motion-picture records of the flights.

The take-off tests were made by rapidly increasing the power to the propellers until the model rose from the ground. The power operator then adjusted the power for hovering and the model was stabilized at various heights above the ground. For the landing tests, the power operator reduced the power so that the model descended slowly until the landing gear was about 8 inches above the ground. At this point, the power was reduced as quickly as possible and the model settled to the ground on the shock struts.

Hovering-flight tests were made in still air at a height of 15 to 20 feet above the ground to determine the basic stability and control characteristics of the model. For all these flights, it was possible to obtain the pilots' opinion of the stability and controllability of the model. In some of the flights, quantitative indications of the stability of the model were obtained by taking motion-picture records of the uncontrolled pitching and yawing oscillations. In other flights, quantitative data on the controllability of the model were obtained by making motion-picture records to show the ability of the pilot to stop the pitching and yawing oscillations after they had been allowed to build up. Hovering-flight tests at altitude were made with both the overhead-cable and trailing-cable techniques to determine whether the cable arrangement had any significant effect on the uncontrolled motions of the model.

Hovering-flight tests were also made near the ground to determine the effect of proximity of the ground on the flight behavior of the model. These tests were made with the tail control surfaces from about 3 to 12 inches above the ground. They consisted entirely of controlled flights since it was impossible to maintain the height of the model in uncontrolled flight.

The transition tests were made by starting with the model hovering in the test section of the full-scale tunnel at zero airspeed. As the airspeed was increased, the pitch pilot tilted the model progressively farther into the wind to maintain its location in the test section during the transition. These flights were slow constant-altitude transitions covering a speed range from about 0 to 45 knots, which corresponded to full-scale airspeeds of about 0 to 125 knots. Since small adjustments or corrections in the tunnel airspeed could not be made readily, the pitch pilot and power operator had continually to make adjustments to hold the model in the center of the test section. Flights were also made in which the airspeed was held constant at intermediate speeds so that the stability and control characteristics at constant speed could be studied.

Flights were made to determine whether the model could be flown sideways at fairly high translational speeds. A full-scale airplane of this type might have to make a landing approach in this manner because of the limited visibility along the Z-axis. The technique used for these tests was the same as that used for the forward flights. The tests were started with the model in hovering flight, and as the airspeed was increased the controls were operated so that the model flew sideways into the wind. These tests covered a speed range of about 0 to 10 knots. These flights were necessarily of limited duration since they took place while the tunnel speed was building up to the minimum steady speed of 23 knots provided by the tunnel control.

The center of gravity was arbitrarily set at 0.12 mean aerodynamic chord for the hovering tests and was at the leading edge of the mean aerodynamic chord for the transition tests. The vertical position of the center of gravity was approximately 0.05 mean aerodynamic chord above the thrust line for all test conditions.

On either tail, the control actuators moved each surface $\pm 15^{\circ}$ from the trim position for either pitch, yaw, or roll control. When the X-tail was mounted on the model the rudder and elevator controls were superimposed.

RESULTS AND DISCUSSION

The results of the present investigation are more clearly illustrated by motion pictures of the flights of the model than is possible in a written presentation. For this reason a motion-picture film supplement to this paper has been prepared and is available on load from NACA Headquarters, Washington, D. C.

Hovering Flight

One of the main results of this investigation was that there was no noticeable difference in the behavior of the various model configurations in hovering flight. For brevity and clarity, therefore, in the following discussion of the hovering-flight tests all configurations are discussed as one model and only typical examples are given in the figures.

Hovering flight at altitude.- The hovering flights in which one pilot operated all the controls demonstrated that the model could be flown satisfactorily by a single pilot without any automatic stabilization. It was found that a single pilot could fly the model for an indefinite length of time, and a long flight using this technique is shown in the film supplement to this paper. Because considerable concentration was required for the pilot just to fly the model under these conditions, the detailed studies of stability and control in this investigation were made with three pilots flying the model.

In all configurations the model could be flown smoothly and easily in hovering flight and could be maneuvered to any desired postion in either yaw or pitch. Figures 6 and 7 present time histories of flights in which the pilots intentionally moved the model from one location to another in the test area and flew it steadily for a short time in each location. Figure 6 presents flights with the unswept wing and +-tail, while figure 7 presents flights with the swept wing and +-tail. It is evident from these records that the pilot could move the model rapidly from one position to another and restore it to a fairly steady flight condition quickly in either pitch or yaw with very little overshoot or evidence of a tendency to overcontrol.

Time histories of the uncontrolled pitching motions with the +-tail and yawing motions with the ×-tail are presented in figures 8 and 9, respectively. These figures show that the model had unstable pitching and yawing oscillations. The time histories are not symmetrical about the horizontal axis in all cases because the model could not be trimmed perfectly. The oscillation is superimposed on the aperiodic motion caused by the out-of-trim moments. The records shown in figures 8 and 9, as well as all other figures in this paper, are from flights made with the overhead-cable arrangement. The tests that were made with the trailing-cable technique showed that the cable arrangement had very little effect on the uncontrolled motions of the model. Unstable oscillations occurred with both arrangements and the only noticeable difference was that the instability of the pitching motion for the trailing-cable arrangement seemed to be somewhat less than that for the overhead-cable arrangement.

The pitch and yaw controls in all configurations were very powerful and it was relatively easy for the pilot to stop the pitching and yawing motions of the model. As a demonstration of the controllability of the model, the pilot at times allowed the pitching and yawing oscillations to build up and then applied the controls to stop the oscillation, as shown in figures 10 and 11. Figure 10 shows the pitching motions being stopped (with the +-tail) and figure 11 shows the yawing motion being stopped (with the ×-tail). These data indicate that the pilot could stop the oscillations and return the model to a near vertical attitude in less than 1 cycle. The fact that the model did not return to zero displacement is not significant since the pilot was not making any effort to stop the model over a particular spot or to return it to zero displacement. In stopping these oscillations, the pilot had no tendency to overcontrol or to reinforce the oscillation. The ease with which he could stop the oscillations can probably be attributed to the fact that the periods of the oscillations were fairly long as well as to the fact that the controls were powerful.

The rolling motions of the model in all configurations were neutrally stable in hovering, as would be expected for this type of vertically rising airplane. It was found, however, that the model could be controlled in roll fairly easily, although at times difficulty was experienced because of abrupt changes in roll trim occurring at fairly long intervals. Other models of this type tested by the Langley Free-Flight Tunnel Section have experienced these random trim changes when flown indoors in the same test area. When these models were flown outdoors on a calm day, however, the random trim changes were greatly reduced in magnitude and caused little difficulty in flying the models. Previous force tests on the same propellers indicated that the random changes in trim resulted from fluctuations in the induced flow, particularly near the periphery of the propeller. These fluctuations in inflow appeared to be caused by the random recirculation of the propeller slipstream in the test area.

It might be inferred from these results that full-scale propeller-driven airplanes of this general type would experience difficulty with roll trim when hovering in gusty winds or in the turbulence created by the recirculation of the propeller slipstream from nearby structures.

The model, of course, had no vertical-position stability but had positive rate-of-climb stability because of the pronounced inverse variation of the thrust of the propellers with axial speed. This rate-of-climb stability tended to offset the effect of the time lag in the thrust control so that the model could be maintained at a given height fairly easily.

Hovering near the ground.- In hovering flight with the tail control surfaces at least 6 inches above the ground, it was easy to maneuver the model or to keep it hovering over a spot for a considerable length of time. At heights less than 6 inches the model was more difficult to fly and an uncontrollable oscillation often built up in spite of the pilots' efforts to control the motion. This result might be explained by the data obtained on a similar tail-sitter vertically rising airplane model previously tested by the Langley Free-Flight Tunnel Section. These data indicated that there was a reduction and a change in direction of the slipstream velocity over the rear part of the model as it neared the ground; this change in slipstream velocity caused a reduction in static control effectiveness and presumably also caused a reduction in the damping in pitch and yaw.

The ground-effect tests of the present investigation were made with the center of gravity at 0.12 mean aerodynamic chord. It is probable that the model would have been more controllable near the ground with a more forward center-of-gravity location, since experience has shown that such models tend to be more oscillatory with a rearward center-of-gravity location.

Take-Offs and Landings

Figure 12 presents time histories of two representative take-offs and landings in still air. The figure shows the motions of the model in yaw only, because only one camera was used in recording these tests. The behavior of the model, however, was essentially the same in pitch as it was in yaw during take-offs and landings. In general, take-offs and landings were easy to perform because the model responded quickly to control deflection and could be maneuvered fairly easily after leaving the ground. In most of the take-offs, the model moved sideways just as it was leaving the ground. The pilot could not prevent this motion but could usually limit it to less than one-half span. This behavior is believed to result mainly from the fact that the model had little excess thrust so that it could not take off rapidly and thereby minimize the time spent at heights at which ground effect reduced the control effectiveness. Since the control surfaces were trimmed for hovering at a considerable height above the ground, these settings were not sufficient for trim in the region where the control effectiveness was low. Landings on a given spot could be made accurately with all model configurations.

Transition Flight

Changing the tail configuration made no difference in the stability and control characteristics of the model with either the swept or the unswept wing in transition flight. The ×- and +-tails, therefore, are not discussed separately in the following sections and only typical examples are given in the figures. There were some differences, however, in the behavior of the model with the swept and with the unswept wings in transition flight and these differences are, of course, discussed in the following sections.

Pitch characteristics.- Time histories of two transition flights, showing the pitching and yawing motions of the model while the forward speed was slowly increased, are presented in figures 13 and 14. Figure 13 shows a representative flight of the model with unswept wing and +-tail, and figure 14 shows a flight of the model with swept wing and +-tail. Except at the start of the transition, where the pitch pilot had some difficulty at times in keeping the model from nosing up and drifting back in the test section, the model in all configurations was easy to fly in pitch and seemed to have stability of angle of attack over most of the speed range. At times, the model would fly "hands-off" in pitch for reasonably long periods of time when it was trimmed correctly and the airspeed was not being changed. The rapid variations in angle of pitch about the mean value, which are evident in figures 13 and 14, did not seem to be caused by poor stability but appeared, rather, to result partly from the difficulty in coordinating thrust and pitch control as the airspeed increased and partly from overcontrolling because the control deflection for pitch was excessive at the higher speeds. In comparing the pitching motions of the unswept wing as shown in figure 13 with those of the swept wing in figure 14, it would seem that the swept-wing configuration was not as easy to fly smoothly in pitch as the unswept-wing configuration. This was caused mainly by the fact that the yaw and roll pilots were having some difficulty with the swept-wing configuration, which was reflected in the pitching motions of the model and was not caused by any appreciable differences in the longitudinal stability of the model.

A plot of the average variation of trim angle of pitch with airspeed for steady flight during transition in all configurations is presented in figure 15. These angles of pitch are averages taken from the motion-picture records of several flights at different forward speeds when the model appeared to be in steady-flight condition. It was probably necessary to fly at a slightly lower angle of pitch with the model than would be required for a full-scale airplane to attain the same speed because of the added drag of the propeller guard and the power and control cable. It is believed, however, that these differences in operating conditions will not materially affect the main results of this investigation.

Yaw characteristics.- It was found that for the unswept-wing configuration the uncontrolled yawing motion was divergent in the very high angle-of-pitch range but could be controlled easily. As the forward speed of the model increased and the angle of pitch became lower, the model tended to become stable in yaw. The record of the yawing motion in figure 13 does not show the difference between the high and low angle-of-pitch ranges, but the record of the rudder deflections in figure 13 shows that in the high angle-of-pitch range where the yawing motion was divergent the yaw pilot had to apply control frequently, whereas at angles of pitch below 35° the pilot applied fewer control motions and could let the model wander in the test section for short periods of time. In this condition the flicker controls seemed very powerful and the control deflections (which were needed for hovering and for the first part of the transition) were too great for smooth flight. For this reason the flight records indicate an undue amount of yawing in flight, particularly at low angles of pitch, which would not be expected to occur with a full-scale airplane in which small control deflections can be obtained and in which the controls can be coordinated smoothly.

The yaw characteristics of the model in the swept-wing configuration were about the same as for the unswept-wing configuration except in the range of pitch angles between 40° and 30°. In this range the behavior of the swept-wing configuration was somewhat erratic in sideslip and the model tended to trim on either side of zero yaw and roll. This tendency is not clearly shown in the time histories of the yawing motion in figure 14, but the control records show that in the 40° to 30° angle-of-pitch range both the yaw and the roll pilots were working harder to trim the model in the swept-wing configuration than in the unswept-wing configuration.

Roll characteristics.- No difficulty was experienced in roll during the transition flights with the unswept-wing configuration, and at all forward speeds the model was easier to control in roll than it was in hovering flight. This was also true for the swept-wing configuration except in the 40° to 30° angle-of-pitch range where the aforementioned sideslipping tendency occurred. In the unswept-wing configuration the model seemed to be stable in roll at all forward speeds covered in the tests and, as shown in figure 13, after trimming the model to account for the change in trim with speed the roll pilot had to use little or no control.

As soon as the tunnel air flow started, the random roll trim changes experienced with all configurations in hovering flight appeared to be eliminated. This result is again in agreement with the results obtained from similar models previously tested by the Langley Free-Flight Tunnel Section which indicated that even very low forward speeds were sufficient virtually to eliminate random changes in roll trim.

Sideways Flights

There was no noticeable difference in the behavior of the different model configurations in sideways flight. In all configurations the model was fairly easy to control in roll in hovering flight but, as the sideways airspeed was increased, it had an increasingly strong tendency to diverge in roll and became more difficult to keep oriented with one wing pointed into the wind. Finally, at a speed of about 10 knots, the model would roll off and fly on its belly or back despite the efforts of the roll pilot to control it. This roll-off is illustrated in the film supplement to this paper which shows three representative sideways flights. Again, data from a similar model show that the tendency to diverge was apparently caused by static instability in bank in sideways flight. The force-test data from the similar model indicated that for sideways flight there was an unstable variation of rolling-moment coefficient with angle of roll which increased with increasing speed. The roll divergence encountered in flying the present model occurred when the model inadvertently rolled to an angle at which the rolling moment produced by the instability was greater than the moment that could be produced by the roll control.

SUMMARY OF RESULTS

The results of a dynamic stability and control investigation of a general-research propeller-driven vertically rising airplane model which had swept or unswept wings and ×- or +-tails can be summarized as follows:

1. There was no noticeable difference in the behavior of the different model configurations in hovering flight. In all configurations the model could be flown smoothly and easily in hovering flight and could be maneuvered readily to any desired position despite the fact that the uncontrolled pitching and yawing motions were unstable oscillations. The pilots could stop these oscillations quickly even after they had been allowed to build up to a large amplitude because the periods of the oscillations were fairly long and the control surfaces were powerful. There was a noticeable reduction in the controllability of the model in all configurations when it was hovering very close to the ground.

2. Take-offs could be made easily and landings on a given spot could be made accurately with all model configurations.

3. The characteristics of the model in transition flight were the same with either tail arrangement. Flights through the transition range could be performed fairly easily with the unswept wing. The pitching and rolling motions with the unswept-wing configuration were easy to control and the model seemed to have stability of angle of attack and angle of roll over most of the transition range. The yawing motion was divergent in the very high angle-of-pitch range but could be controlled easily. As the forward speed increased and the angle of pitch became lower the model tended to become stable in yaw. The characteristics of the swept-wing configuration in transition flight were about the same as those of the unswept-wing configuration except at angles of pitch between 40° and 30°, where the behavior of the model in sideslip was somewhat erratic.

4. It was possible to fly sideways at speeds up to about 10 knots with all configurations. Above this speed the model diverged uncontrollably in roll.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 28, 1956.

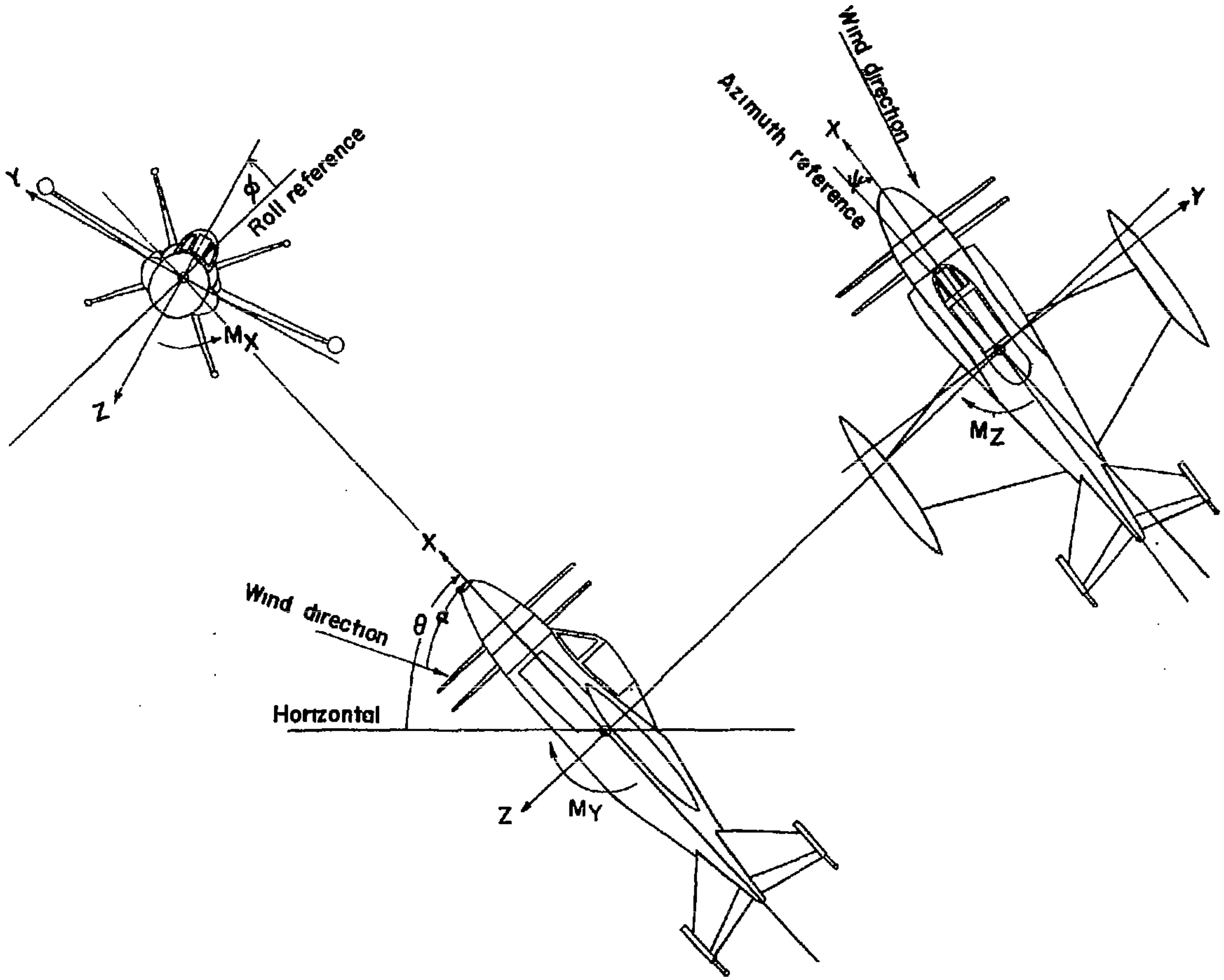


Figure 1.- The body system of axes. Arrows indicate positive directions of forces, moments, and linear and angular displacements.

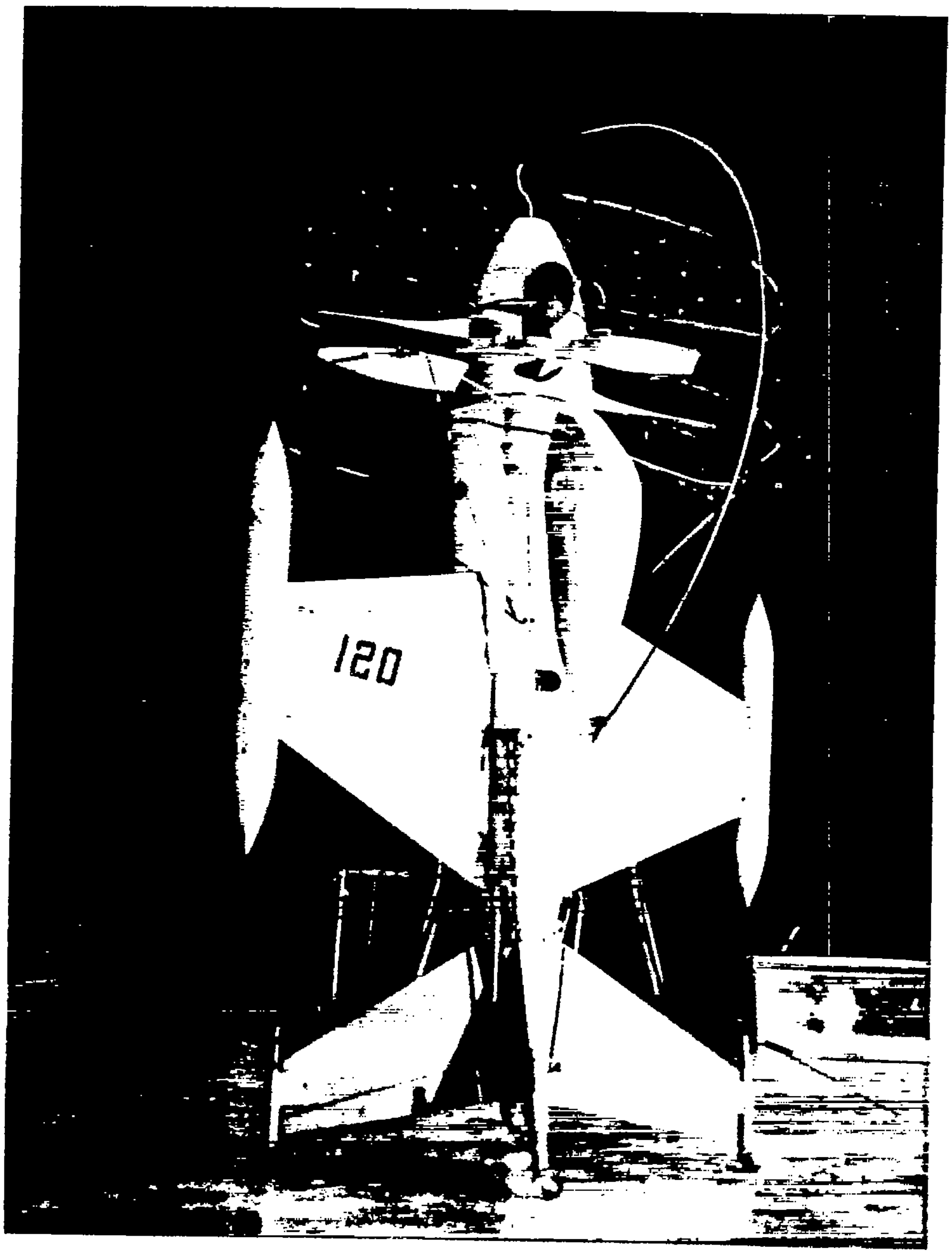
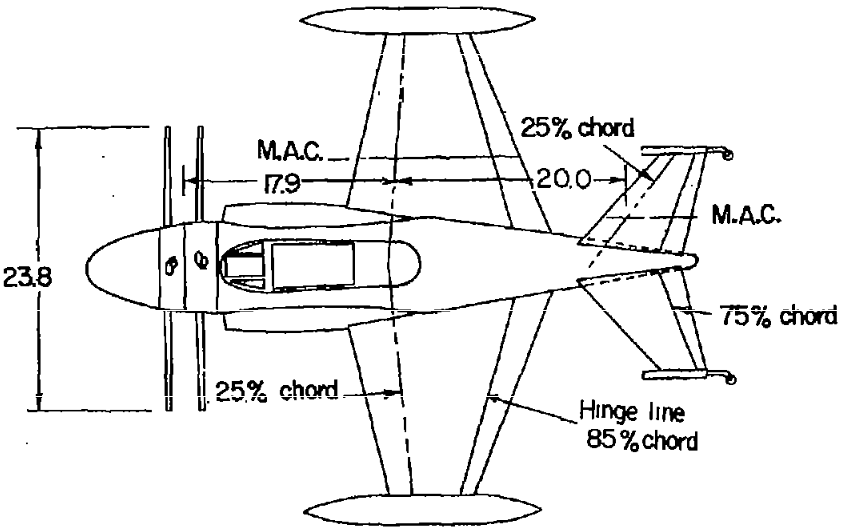
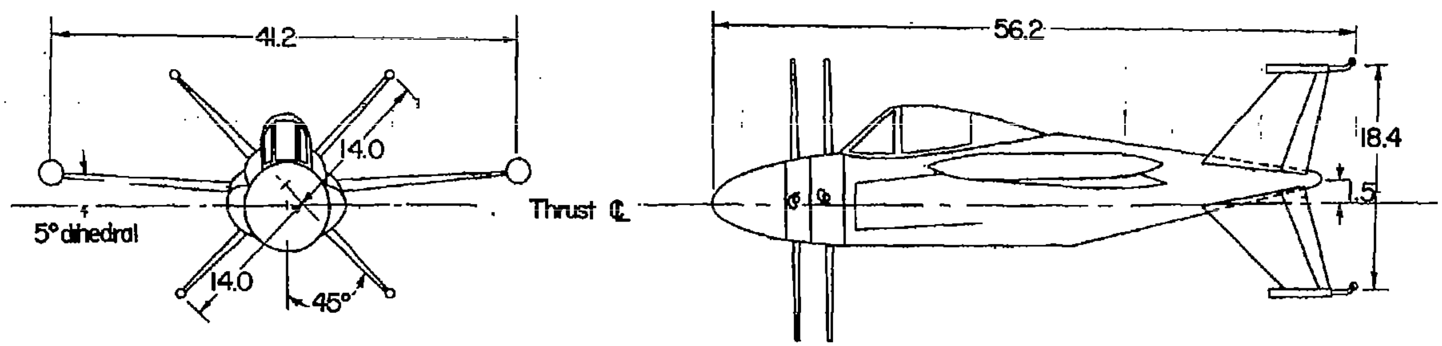


Figure 2.- Model with unswept wing and X-tail. L-82882.1

GENERAL SPECIFICATIONS

WING:	
Area, total, sq in.	553.4
Aspect ratio	3
Sweep $\frac{c}{4}$, deg	5.7
Chord, in.	
Root	20.25
Tip	6.63
Airfoil section, root and tip	NACA 64A206 (Mod)
Mean aerodynamic chord, in.	14.6
Incidence - root and tip, deg	1
Pods	
Length, in.	21
Diameter, in.	2.25
TAIL SURFACES:	
Area, total, sq in.	380
Sweep $\frac{c}{4}$, deg	30
Chord, in.	
Root	10.62
Tip	4
Airfoil section, root and tip	NACA 65A007
Incidence - root and tip, deg	-4 (L.E. down)



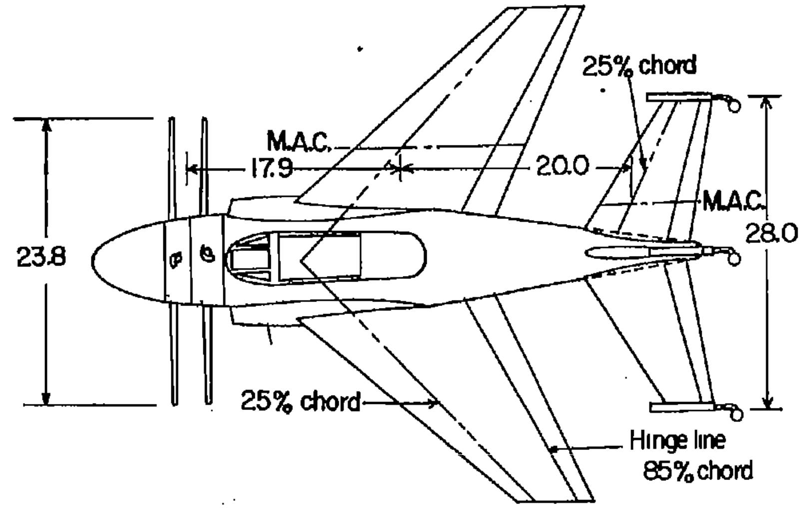


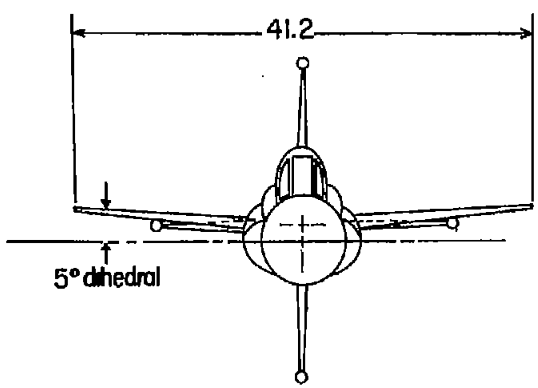
(a) Unswept wing and x-tail.

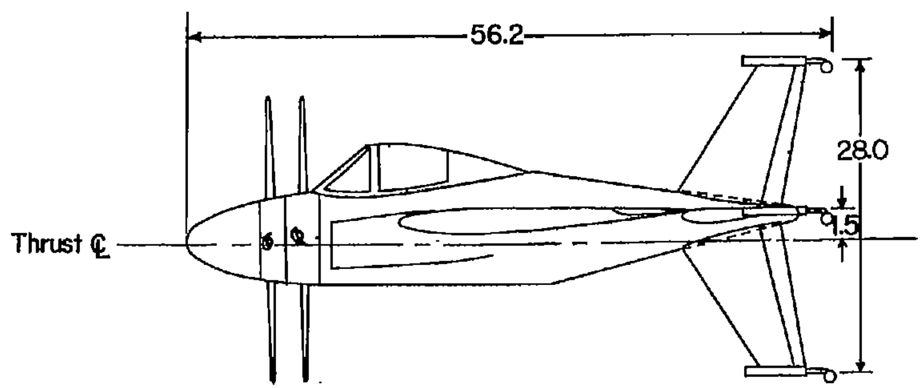
Figure 3.- Three-view drawings of the model. All dimensions are in inches.

GENERAL SPECIFICATIONS

WING:	
Area, total, sq in.	553.4
Aspect ratio	3
Sweep $\frac{c}{4}$, deg	45
Chord, in.	
Root	20.25
Tip	6.63
Airfoil section, root and tip	NACA 64A206 (Mod.)
Incidence - root and tip, deg	1
Mean aerodynamic chord, in.	14.6
HORIZONTAL TAIL:	
Area, total, sq in.	190
Sweep $\frac{c}{4}$, deg	30
Chord, in.	
Root	10.62
Tip	4
Airfoil section, root and tip	NACA 65A007
Incidence - root and tip, deg	-4 (L. E. down)
VERTICAL TAIL:	
Area, total, sq in.	190
Sweep $\frac{c}{4}$, deg	30
Chord, in.	
Root	10.62
Tip	4
Airfoil section, root and tip	NACA 65A007

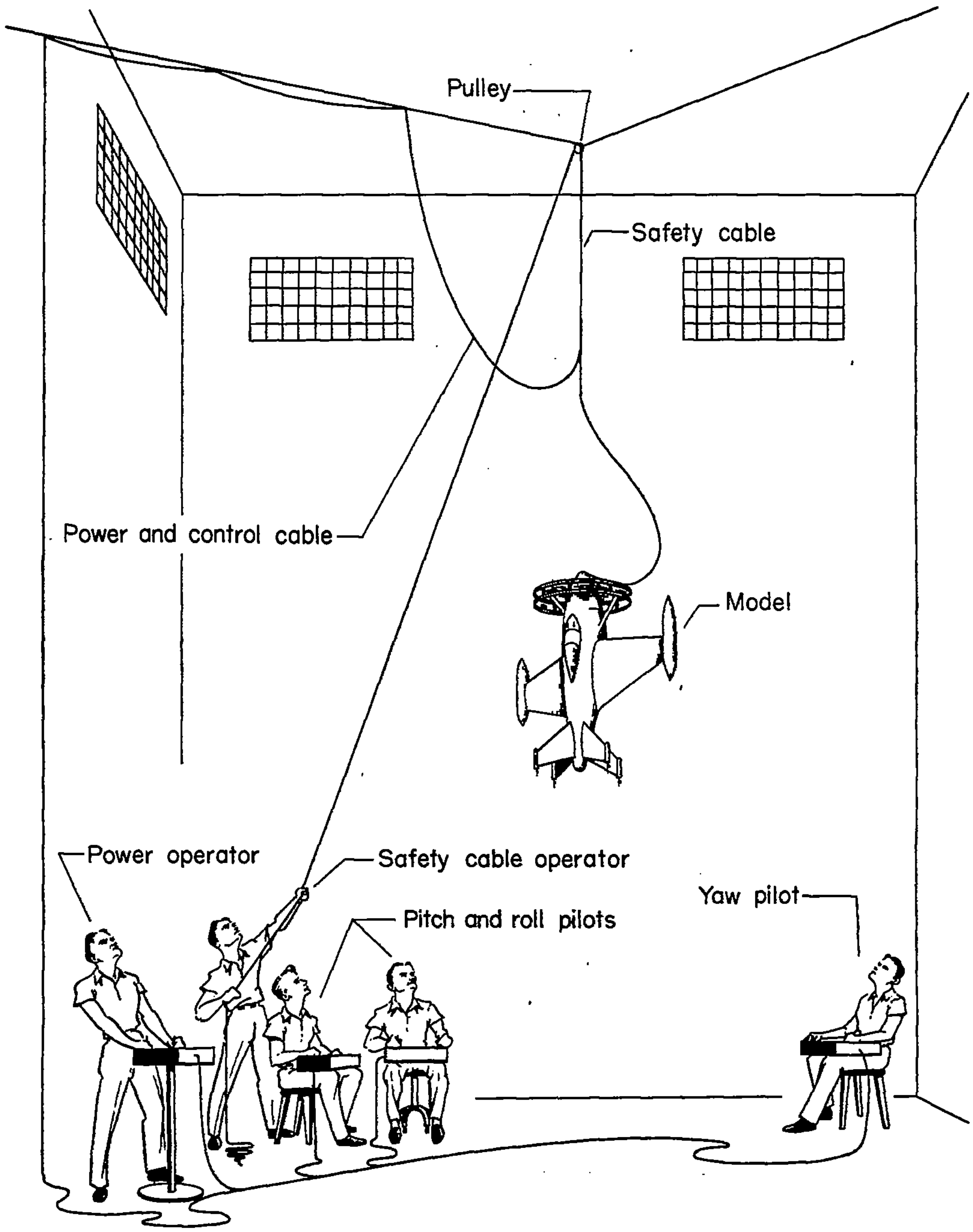






(b) Swept wing and +-tail.

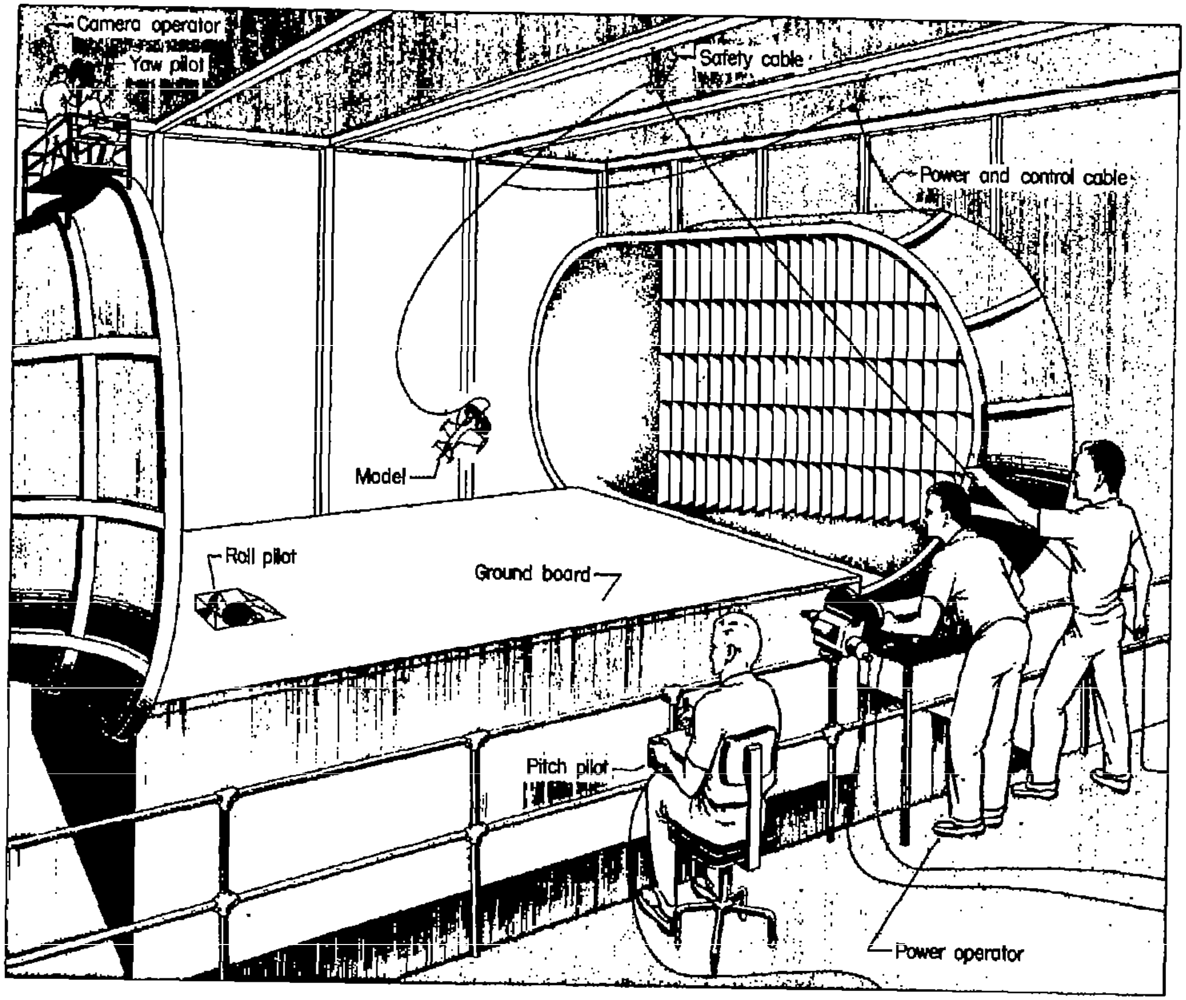
Figure 3.- Concluded.



L-93574

(a) Hovering tests.

Figure 4.- Test setups.



(b) Transition tests. L-93575

Figure 4.- Concluded.

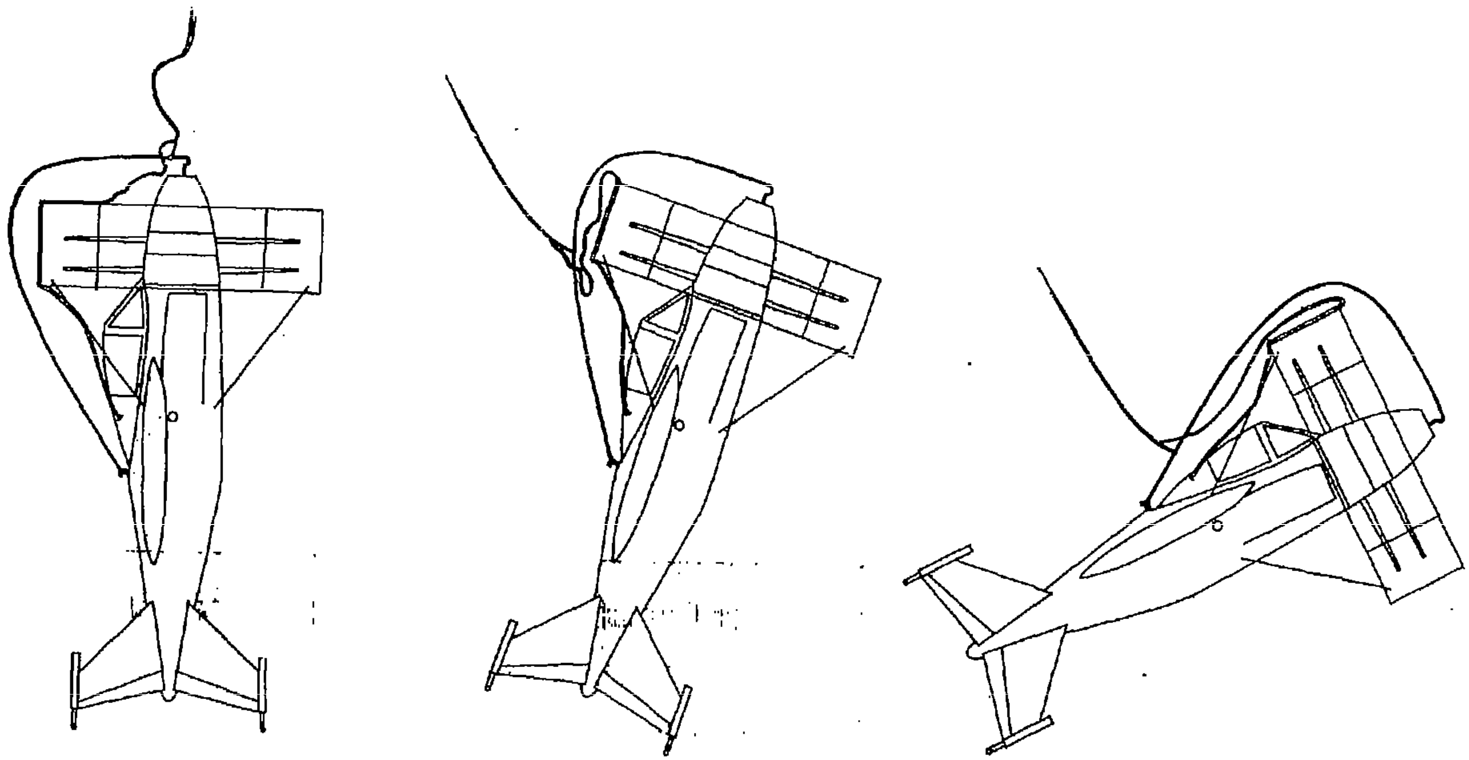
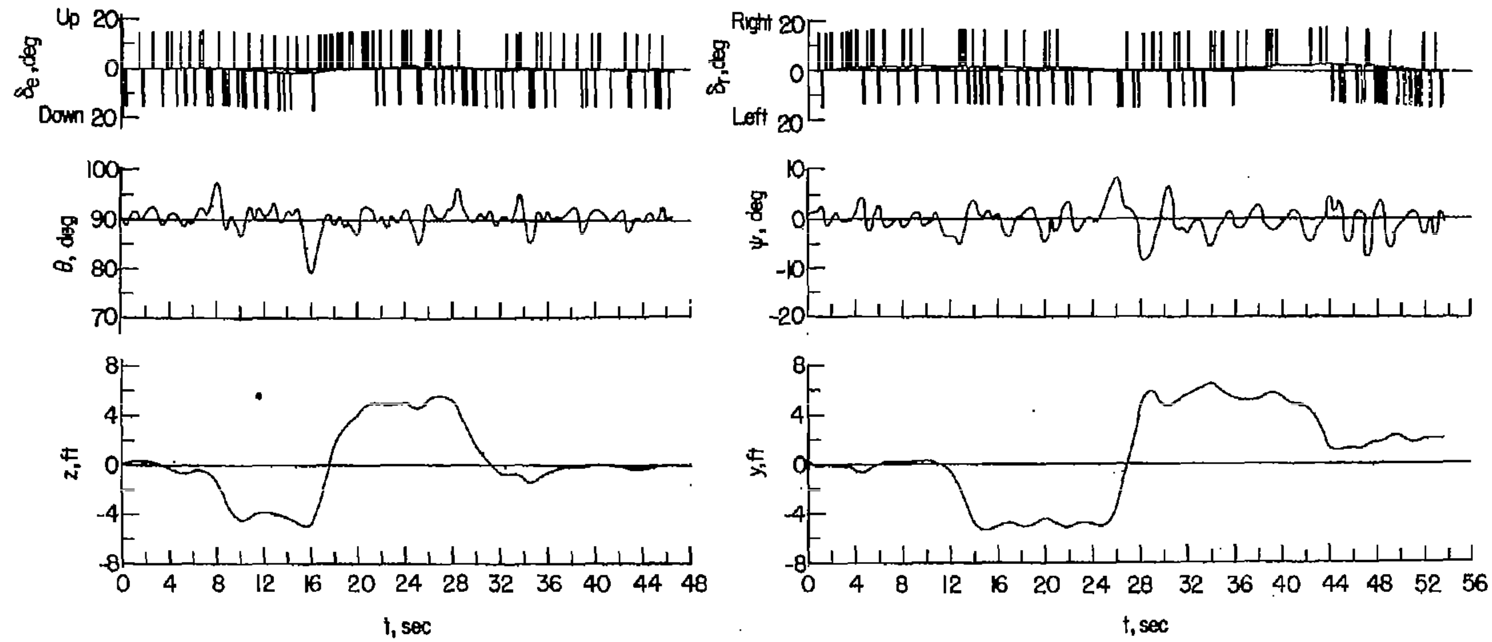


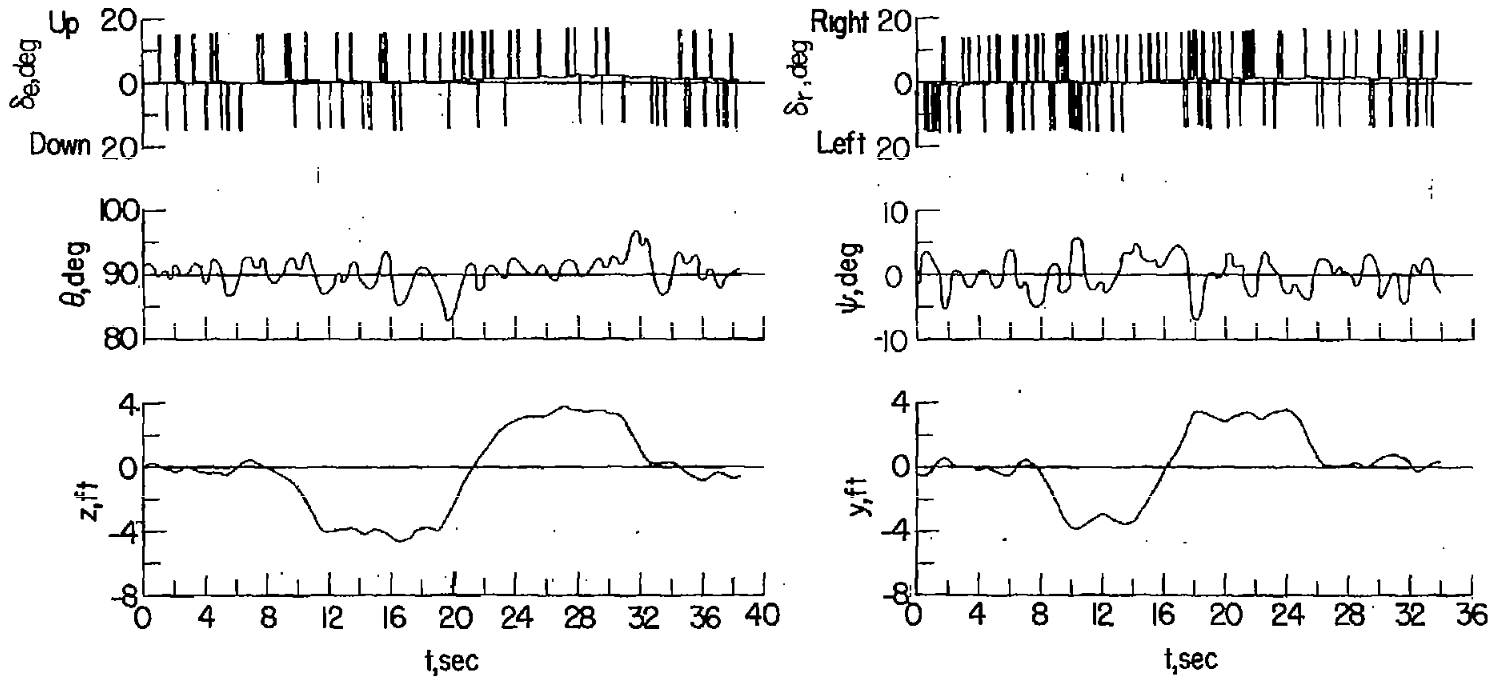
Figure 5.- Method of attaching the safety cable to model during transition-flight tests.



(a) Pitch.

(b) Yaw.

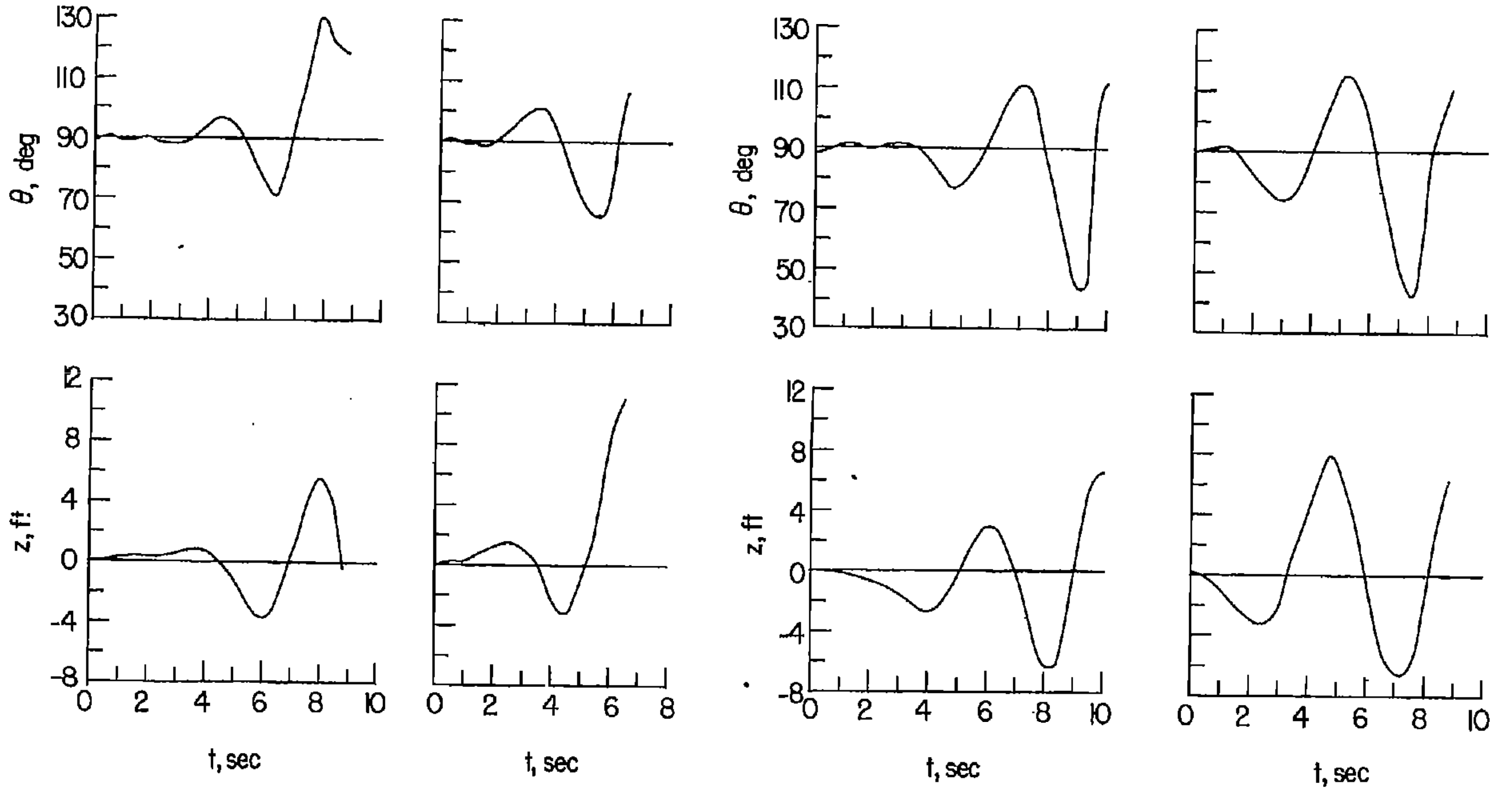
Figure 6.- Time histories of the controlled pitching and yawing motions in the hovering condition, showing the ability of the pilot to fly steadily and maneuver quickly from one position to another with the unswept wing and +-tail.



(a) Pitch.

(b) Yaw.

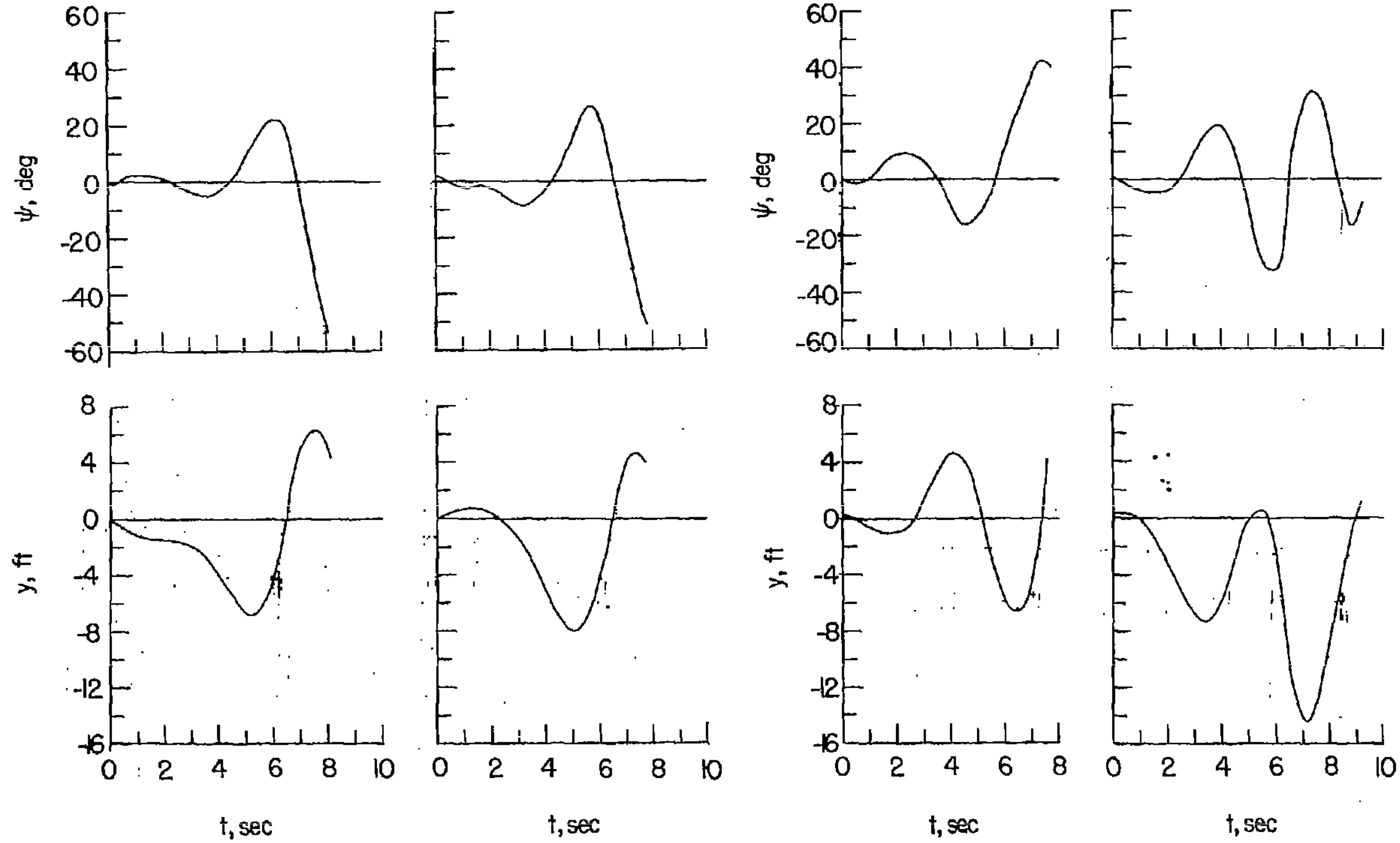
Figure 7.- Time histories of the controlled pitching and yawing motions in the hovering condition, showing the ability of the pilot to fly steadily and maneuver quickly from one position to another with the swept wing and +-tail.



(a) Unswept wing.

(b) Swept wing.

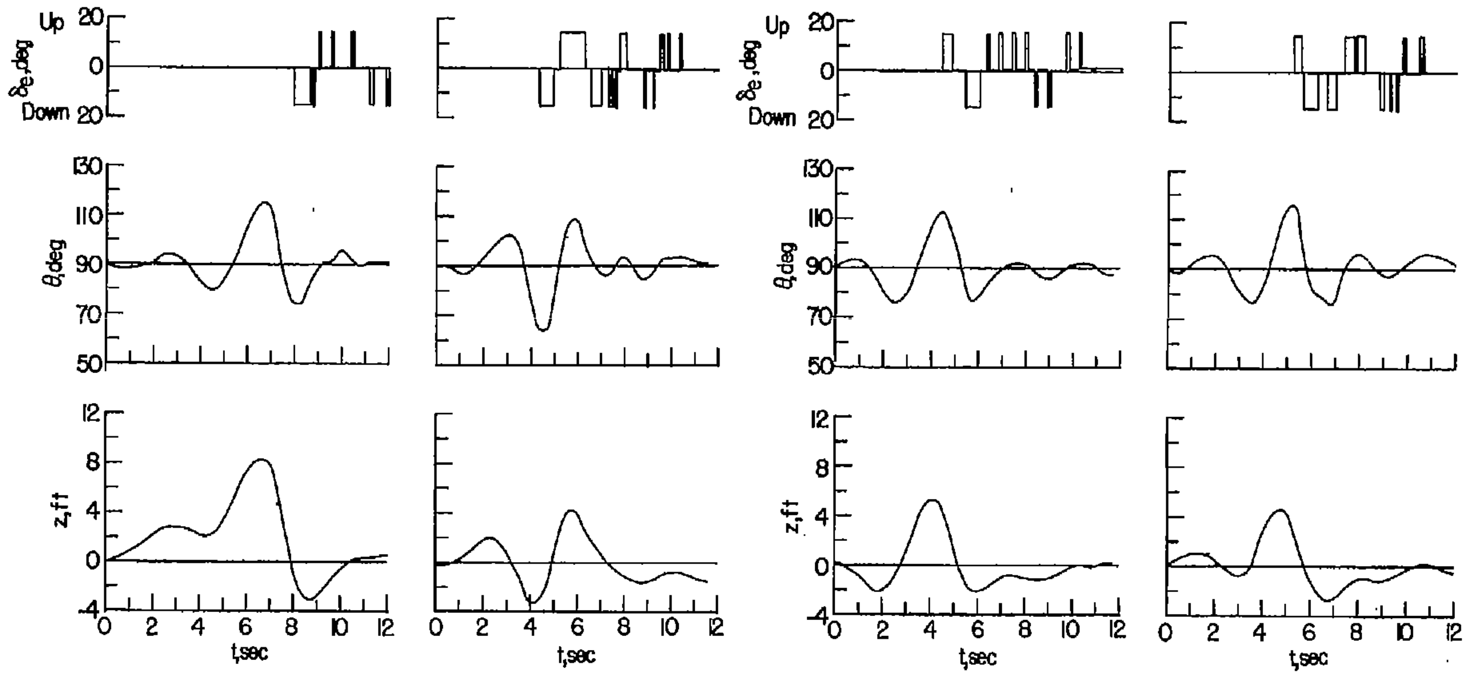
Figure 8.- Uncontrolled pitching motions of the model in hovering flight with the +-tail.



(a) Unswept wing.

(b) Swept wing.

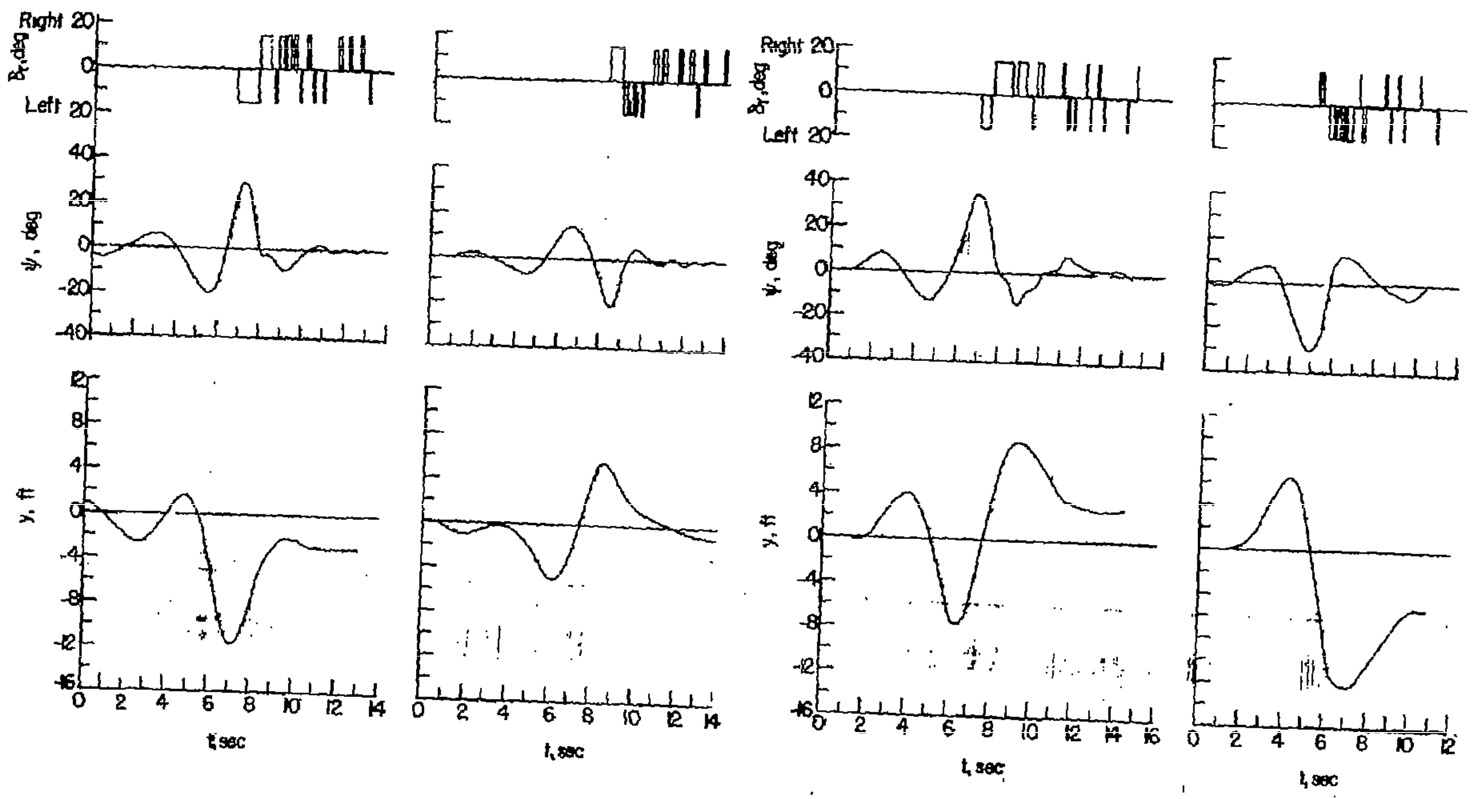
Figure 9.- Uncontrolled yawing motions of the model in hovering flight with the X-tail.



(a) Unswept wing.

(b) Swept wing.

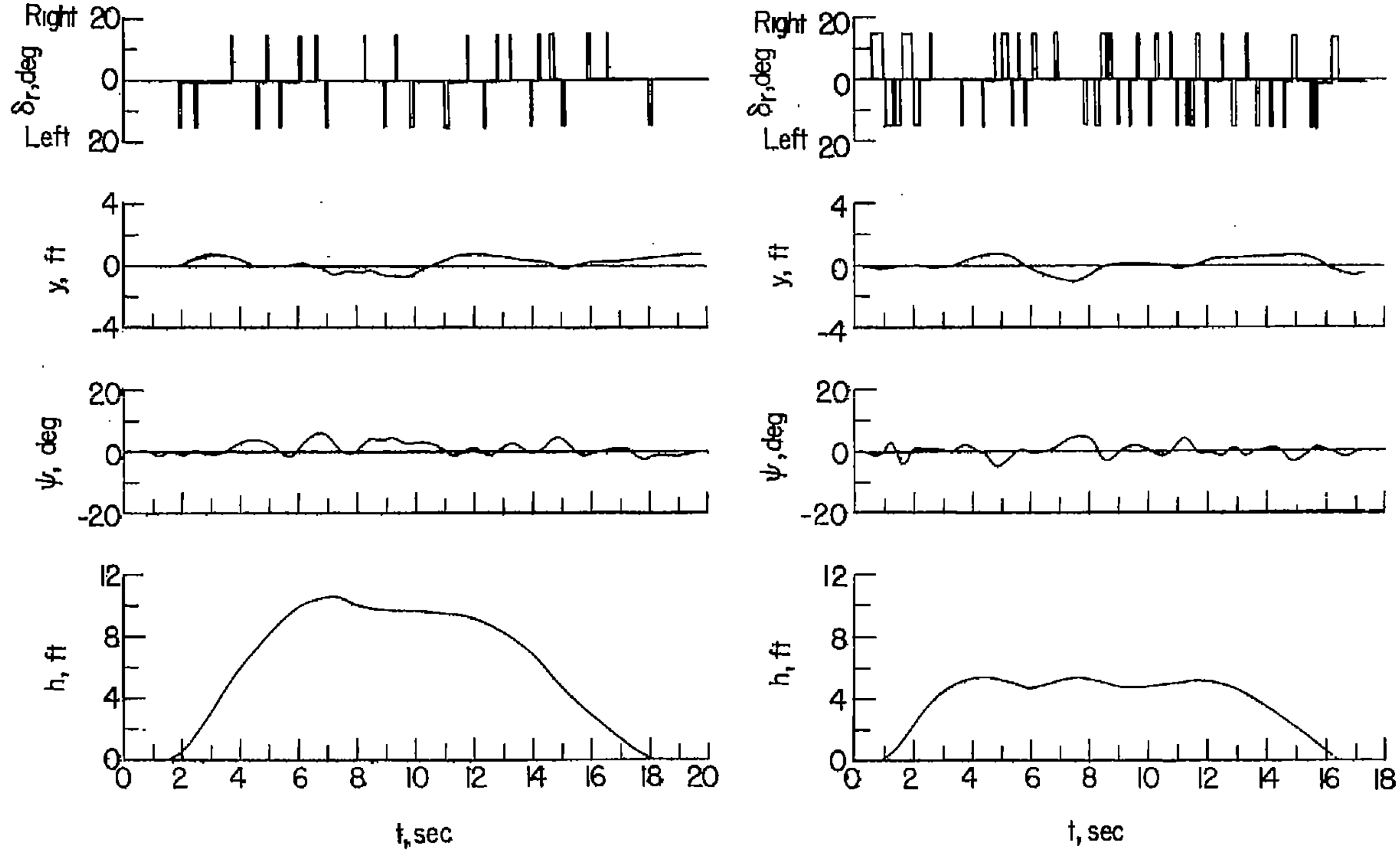
Figure 10.- Time histories of model with the + -tail, showing the ability of the pilot to stop the uncontrolled pitching motions after they had been allowed to build up.



(a) Unswept wing.

(b) Swept wing.

Figure 11.- Time histories of model with the X-tail, showing the ability of the pilot to stop the uncontrolled yawing motions after they had been allowed to build up.



(a) Unswept wing.

(b) Swept wing.

Figure 12.- Time histories of the motions of the model with +-tail during take-offs and landings.

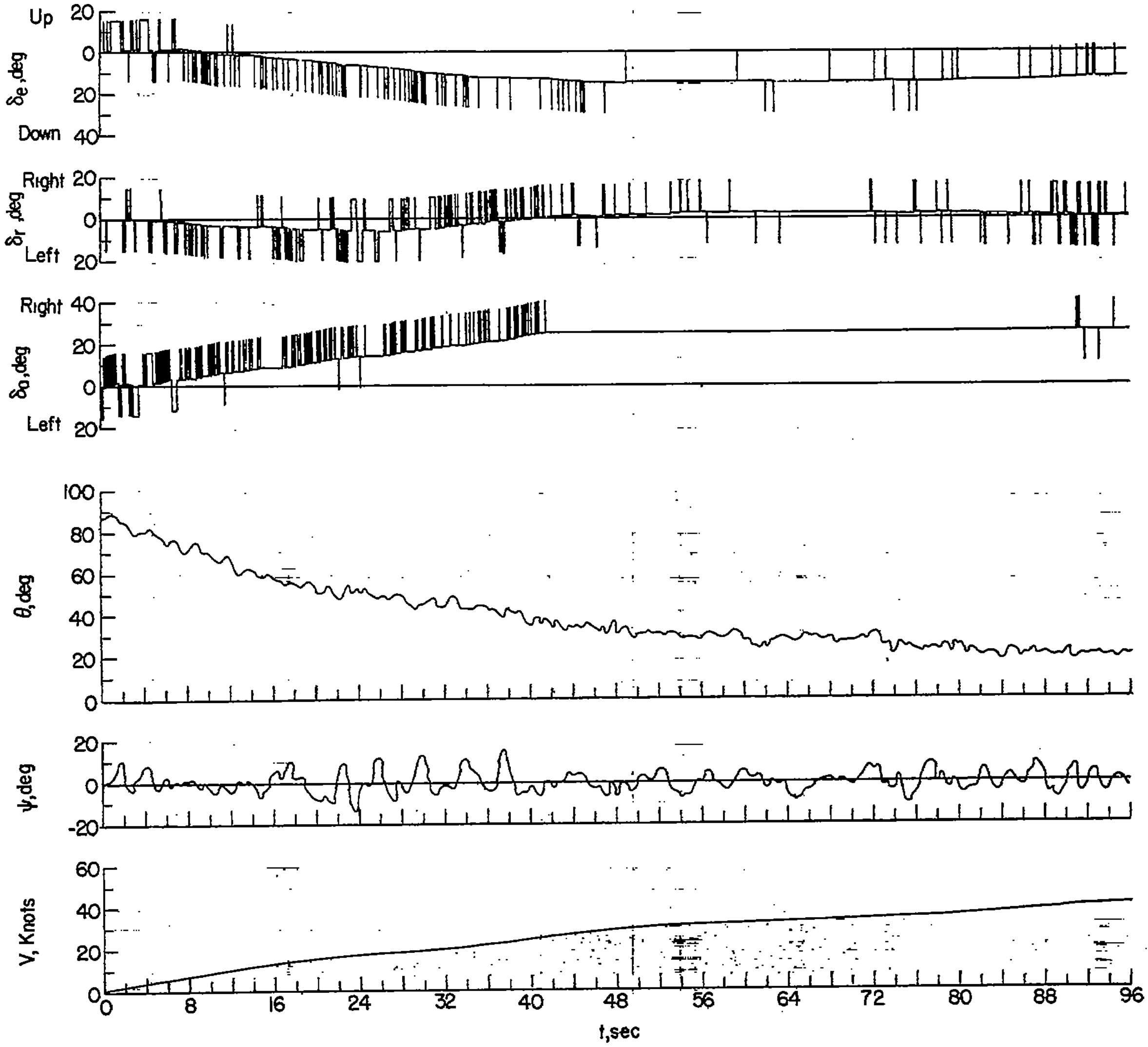


Figure 13.- Time history of the motions of the model with unswept wing and +-tail in constant-altitude transition.

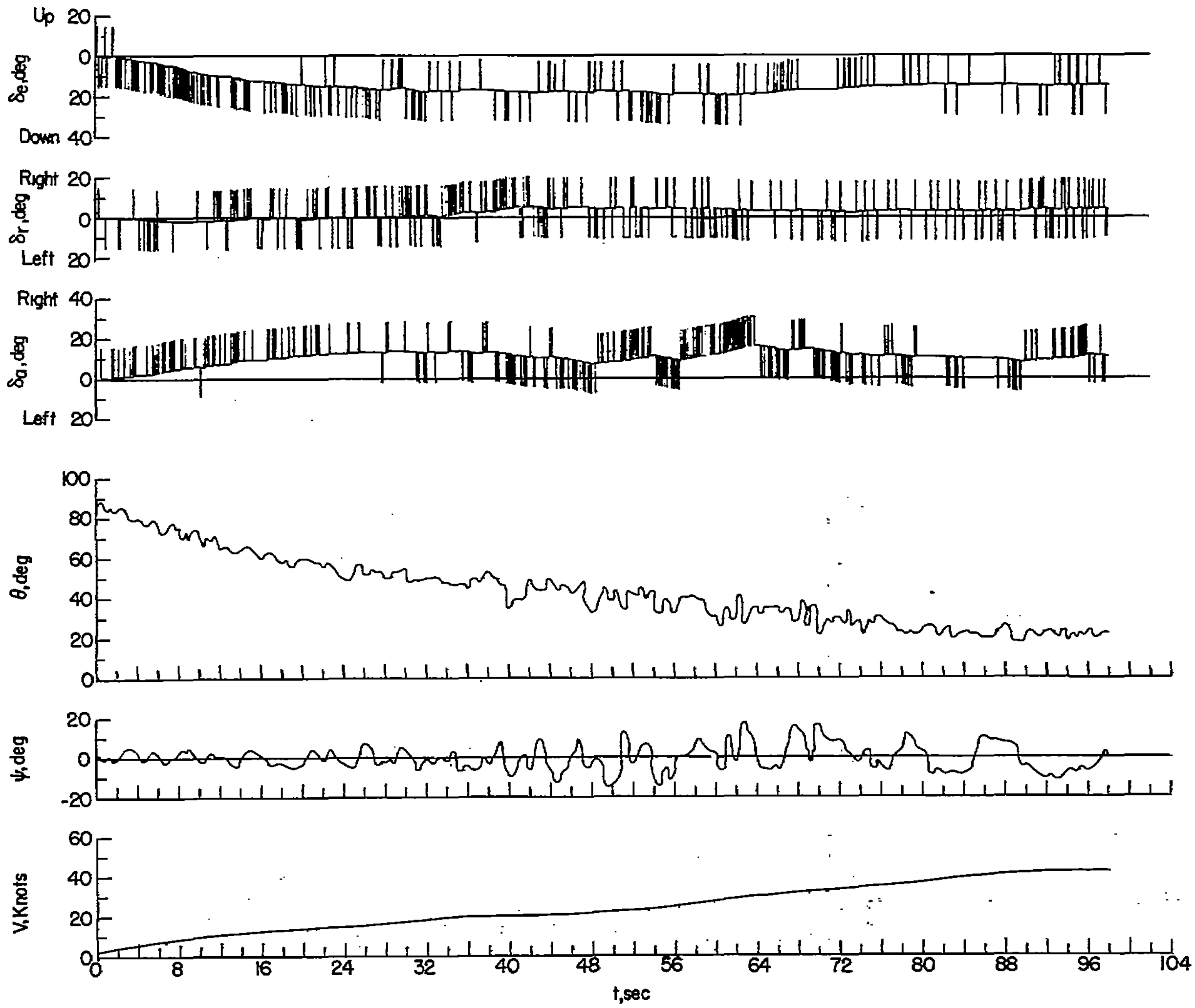


Figure 14.- Time history of the motions of the model with swept wing and +-tail in constant-altitude transition.

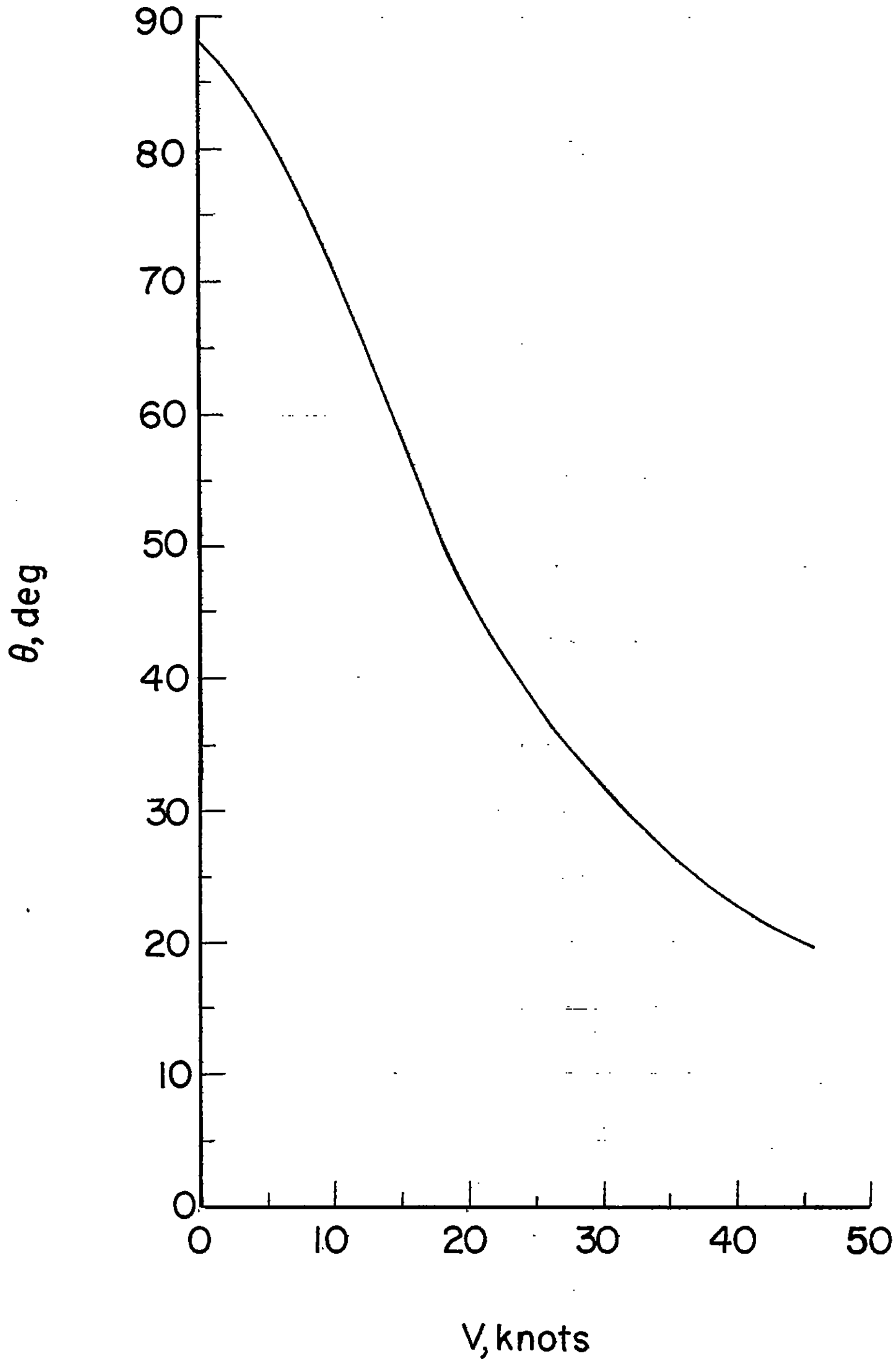


Figure 15.- Variation of angle of pitch with forward transition speed.